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SUCCESSFUL NEW TECHNIQUES IN PROSPECTING FOR PHOSPHATE DEPOSITS

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SUCCESSFUL NEW TECHNIQUES IN PROSPECTING FOR PHOSPHATE DEPOSITS1/

A.5.2.1

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1. Two decades ago, phosphorus was called the bottleneck in alleviating the world's hunger. South America, Asia, and other large areas of the world were thought to have no important local sources of this vital nutrient. The outlook now is much brighter, partly because a few important new deposits have been developed, but mainly because technological and geological advances promise to make phosphate even more widely available in the future.

2. Among these advances, four in the fields of beneficiation and fertilizer technology are of special significance: 1) A variety of washing and flotation techniques make it possible now to produce marketable concentrates from unconsolidated deposits that contain only 5 to 10 percent P_2O_5 (see Ruhlman, 1958, p.10). 2) Newly developed phosphate fertilizers either do not require sulfuric acid or require less than is currently used in making the ordinary varieties of superphosphate, and hence can be manufactured where sulfuric acid is in short supply (Walthall, 1953, p. 205). 3) Certain phosphorites, apparently ones relatively high in hydroxylapatite, have been found to be relatively soluble in soil solutions (as judged by their neutral ammonium citrate solubility); they can therefore be used directly as fertilizers on many soils without prior treatment and hence can be marketed at low cost. Examples are the Curaçao Island deposits, certain of the North African deposits (Jacob and Hill, 1953, p. 336), and the newly discovered phosphorites of the Sechura Desert, Peru (T. M. Cheney, written communication, 1961). 4) Experiments at the Instituto de Pesquisas Agronomicas of Brazil, undertaken in cooperation with technicians of the U.S. Agency for International Development, indicate that common phosphorites, which are relatively insoluble where applied to most soils in temperate climates, can be used directly on acid soils of the tropics (J.L. Haynes, written communication, October 1961). All these developments will help increase the geographic availability and lower the cost of phosphate fertilizers.

3. Equally important in increasing the geographic availability of phosphorite are gains in knowledge of the origin of marine phosphorites. These gains result from extensive studies of the Permian Phosphoria Formation of the western United States (see McKelvey and others, 1953 and 1959) and from analysis of the modern marine environment in which phosphorites are forming (Kazakov, 1937; Brongersma-Sanders, 1957; McKelvey and others, 1953; and McKelvey, 1959). This improved understanding of the origin and occurrence of marine phosphorites provides clues useful in prospecting, for it makes it possible to recognize geographic provinces and geologic formations that are favorable for the occurrence of an important class of phosphorites. It is this topic--geologic clues useful in prospecting, and the genetic basis for them--that is the principal target of this discussion.

Origin and environment of deposition of marine phosphorites

4. The solubility of phosphate in sea water increases with decreasing pH and temperature (Sverdrup and others, 1946, p. 241 and 788), and for this reason it is most concentrated in deep cold waters. Oceanic circulation (a reflection of atmospheric circulation brought about by solar heating combined with the rotation of the

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earth), however, deep-plows the sea and brings these nutrient-rich waters to the zone of photosynthesis in local areas.

5. In an idealized ocean, the main elements of the current system consist of a large circulating gyral in each hemisphere (figure 1), with water cooled in polar latitudes moving toward the equator along the east edges of the ocean, and water warmed in equatorial latitudes moving poleward (see also Fleming, 1957). In this system, cold nutrient-rich waters are brought to the surface in four situations: 1) Where a current diverges from a coast, or where two currents diverge from each other. The effects of cold currents moving toward the equator in bringing cold phosphate-rich water along the coast are abetted by the seaward movement of coastal surface water that results from the combined effects of prevailing wind and Coriolis force, for as the surface water moves seaward, deep cold water wells up to replace it. 2) Where two currents meet to produce turbulence. 3) Along the west edge of poleward-moving density currents. And 4) in high latitudes where highly saline water from the tropics tends to sink as a result of winter cooling (figure 1).

6. Pronounced climatic, biologic, and geologic effects accompany this deep-plowing of the sea, especially in the areas of upwelling produced by divergence. The presence of cold waters along coasts produces coastal fogs and humid-air deserts. Some of the driest areas in the world are of this type--humid air, perhaps some hygrophytic vegetation, but no rain. The Peruvian and southwest African deserts are present-day examples.

7. The naturally fertilized waters that lie alongside these deserts are the lushest gardens of the sea, for the upwelling cold waters there support tremendous quantities of organisms (see Sverdrup and others, 1946, p. 786-787), with diatoms and other phytoplankton at one end of the food chain, and fish, whales, and fish-eating sea fowl at the other. Blooms of dinoflagellates (red tides) and diatoms are characteristic biologic phenomena in upwelling areas, as are the mass mortalities of fish that accompany red tides and may be a consequence of them (Brongersma-Sanders, 1957).

8. The geologic phenomena accompanying upwelling are perhaps most complex of all. Phosphate in the upwelling water becomes less soluble as the pH and temperature increase near the surface and is precipitated either inorganically or biochemically. Some of the organic matter produced in the zone of photosynthesis is winnowed away and dispersed or destroyed by surface currents, but much of it settles to the bottom, producing reducing conditions even along the open sea. Silica is precipitated biochemically through diatoms, silicoflagellates, and sponges; carbonates are precipitated either chemically or biochemically in warmer coastal waters; and salines may form in lagoons that extend into the adjacent deserts. And, of course, guano and guanotized rock are also characteristic deposits in this general environment.

9. These several phenomena may be observed today in many areas of upwelling, especially those along the western margins of the continents, and nearly all the phosphate deposits known on the present sea bottom lie in such areas of divergent upwelling (figure 2). The geologic effects are less well known in the modern ocean, however, than they are in ancient sediments, and to illustrate the characteristics of the sediments formed in the upwelling environment we will turn now to the Permian Phosphoria Formation and associated rocks in the western United States.

The phosphorite facies

10. The sedimentary facies that are found in this environment are summarized in figure 3, which represents an idealized section of rocks deposited synchronously in the Phosphoria sea in Idaho and Wyoming. As shown there, dark carbonaceous shale typically grades shoalward into phosphatic shale, phosphorite, and dolomite; chert; several facies of carbonate rock; and saline deposits and light-colored and red shale.

11. Epeirogenic movements cause these environments to shift laterally. As the sea transgresses and regresses, therefore, the lateral sequence shown in figure 3 comes to be reproduced, in whole or in part, in the same or in reverse order in vertical section, and over the region as a whole shoalward facies overlap and intertongue with deeper-water facies in vertical section. An example of such an intertongued sequence of sediments is shown by the reconstructed cross section of the Phosphoria Formation and its stratigraphic equivalents shown in figure 4.

12. The vertical sequence of lithologies is generally not the complete assemblage of sediments shown in figure 3, nor in exactly the same order shown there, but may be interrupted locally by interbedding of other lithologies. The horizontal sequence too is seldom as regular or complete as shown in figure 3, for the sea bottom may be much more irregular than that idealized diagram implies.

13. In the main, however, the assemblage illustrated in figures 3 and 4 is typical of marine phosphorites deposited in areas of upwelling associated with divergence. Black shale, phosphorite, and chert (or diatomite or cherty mudstone) are the typical rocks, and the vertical sequence is often not unlike that shown in figure 4. Formations, such as the Miocene Monterey of California, that do not contain much associated limestone may represent deposition at relatively high latitudes where the temperature is too cool to favor precipitation of carbonate rock. And those phosphatic limestones that are not associated with conspicuous amounts of black shale or chert, such as are common in the Miocene of the Gulf Coast, perhaps were deposited in areas of dynamic upwelling or turbulent mixing along the western edge of warm density currents that occur along the west side of the oceans (figure 1). These currents are not as rich in nutrients nor as cold as the upwelling waters formed by divergence, and in low latitudes they create waters favorable for the precipitation of limestone, yet fertile enough to support moderately rich organic growth.

Clues useful in prospecting

14. Knowledge of the genesis, environment of deposition, and facies relations of the phosphorites provides two general kinds of clues useful in prospecting, one that we might call oceanographic, the other geologic or stratigraphic.

15. The oceanographic clues are based on the distribution of upwelling in modern seas. Because of the relative stability of many continental margins since late Mesozoic time, ocean currents have also been relatively stable. Many areas of present-day upwelling are therefore clues to the general location of upwelling in late Mesozoic and Cenozoic time, and suggest the occurrence of phosphate deposits in rocks and beach sands of adjacent coastal regions. The known phosphate deposits of California, Baja California, Venezuela, Morocco, Senegal, and Angola are examples of such deposits; the phosphate deposits recently discovered by George Nicol in the Sechura Desert of Peru were found by using this approach. One might expect that a search for phosphorites in the vicinity of other areas of modern upwelling would be rewarding--for example, in Chile, Southwest Africa, Dahomey, the Ivory Coast, Rio de Oro, and countries in the vicinity of the Arabian Sea.

16. The present sea bottom in areas of upwelling also contains phosphate deposits that perhaps can be recovered by dredging (Mero, 1961). Very likely most guano deposits in the vicinity of upwelling have been discovered already, but phosphatized rocks formed from the leaching of older guano deposits, that are themselves now wholly destroyed, have been less well prospected.

17. The geologic clues helpful in searching for phosphate deposits are those furnished by the presence of companion members of the phosphorite family, principally black bituminous shale and chert or other siliceous rocks. Almost any marine black bituminous shale or bedded chert (generally excepting those cherts that are interbedded with volcanic rocks or other thick eugeosynclinal sequences of sediments) may be presumed to have associated phosphorite or phosphatic shale, although perhaps not in deposits of mineable thickness or quality. Analysis of regional lithofacies relations may make it possible to use other members of the family of sediments shown on figure 3--red beds and salines, for example--to identify the horizons that may be laterally favorable for the occurrence of phosphorite.

18. A sparkling example of the application of the geologic approach to prospecting is afforded by R. P. Sheldon's discovery of phosphorite in the Upper Cretaceous sediments of the Gaziantep region of Turkey in August 1962. Sheldon, working under a U. S. Geological Survey project sponsored by the Government of Turkey and the U. S. Agency for International Development, began his search for phosphate with a search of the literature in an analysis of paleogeographic and lithofacies relations in Turkey, next

examined gamma-ray well logs in an attempt to identify specific phosphate-bearing horizons, and then studied in the field the favorable areas and horizons so defined.

19. Sheldon's use of gamma-ray logs deserves special mention, for it illustrates a tool useful in prospecting unexplored terranes. Most marine phosphorites contain 0.005 to 0.02 percent uranium, enough to be detected not only in gamma-ray well logs but also, under favorable circumstances, by aerial radiometric reconnaissance. However, the phosphorites rich in hydroxylapatite (Sechura, Peru, for example) and most guanotized rocks generally contain little or no uranium, so this method may not be applicable to them.

20. In phosphorite prospecting it is worth stressing that many phosphorites, especially those associated with black shales, are likely to be concealed or, at best, poorly exposed, and must be prospected by trenching or test-pitting. Moreover, phosphorite is not a highly distinctive rock, and those not familiar with its appearance may overlook it in hand specimen or outcrop. One valuable aid in identifying it in the field is that the phosphatic grains are generally pelletal, oolitic, nodular, or pisolitic. A simple and generally reliable field test is that a few drops of concentrated hydrochloric acid on rocks containing more than 5 to 10 percent P_2O_5 will produce a white spot, the density of which is roughly proportional to the phosphate content (Gardner, 1944, p. 16). A similar coating or bloom often forms naturally on weathered surfaces. Semiquantitative analyses of phosphate may be made in the field by the method described by Shapiro (1952).

21. In addition to the marine phosphorites deposited in the upwelling environment, other kinds of phosphate deposits are economically important, and are probably more abundant than heretofore recognized. The phosphatized rocks derived from guano have already been mentioned; other important types are residual phosphate deposits, including those concentrated at ancient unconformities, and apatite deposits of igneous origin which are commonly associated with alkalic intrusives. Areas favorable for the occurrence of minable phosphate deposits are widespread, and we may fully expect more intensive prospecting to increase the availability of this vital nutrient in many areas of the world.

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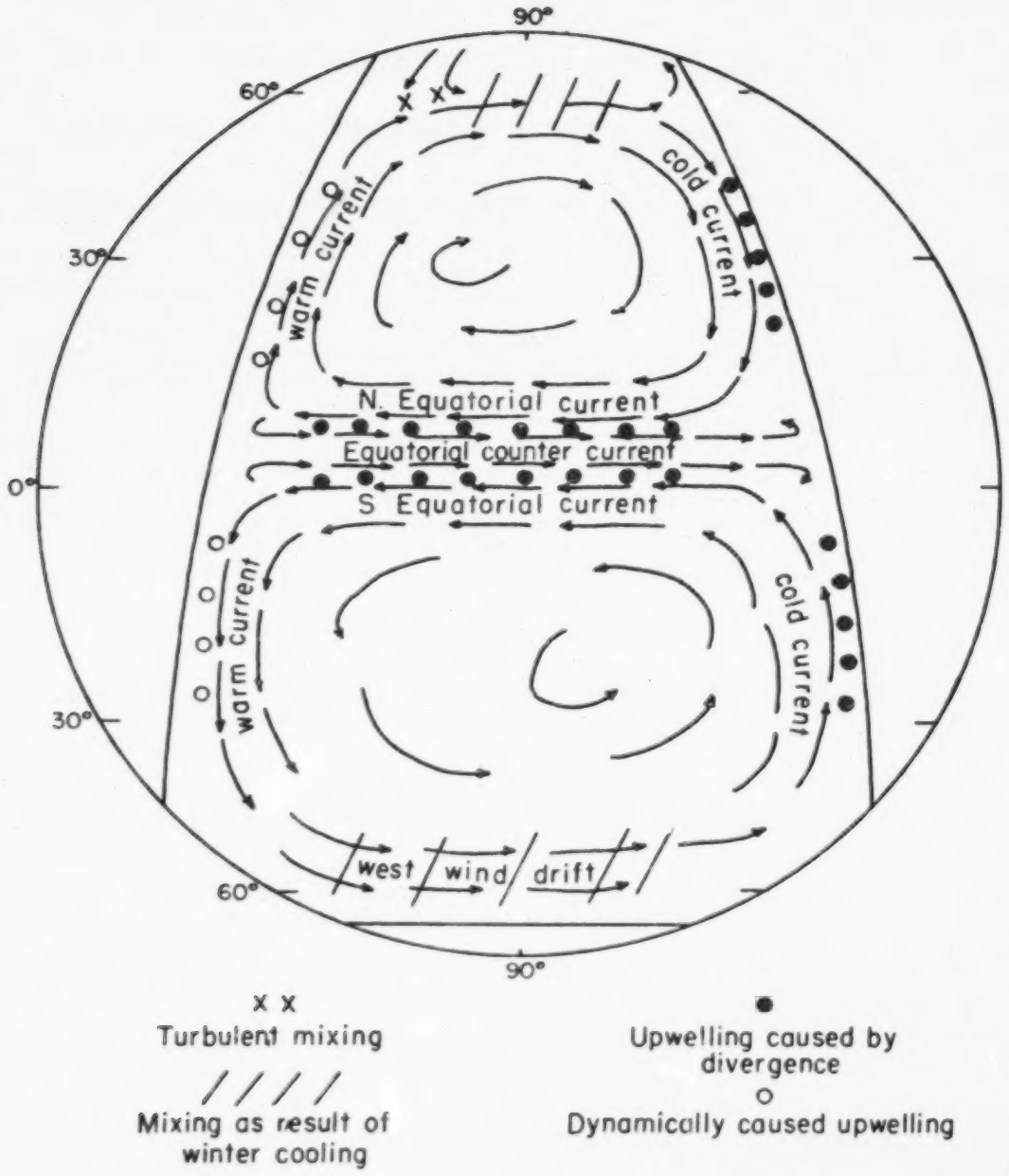

Figure I - Surface currents in an idealized ocean, showing areas of ascending, nutrient - rich water (See Fleming, 1957)

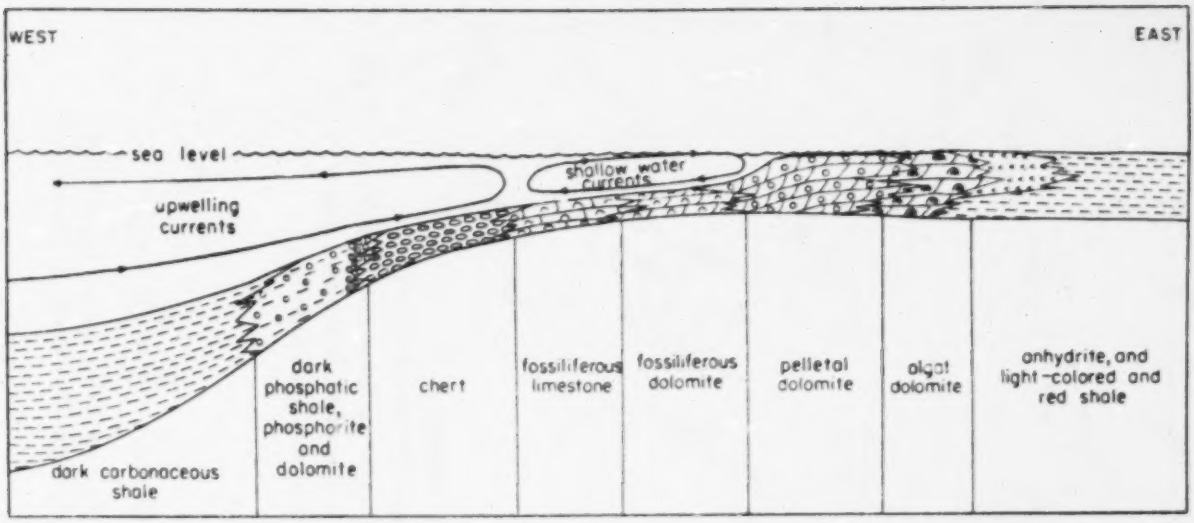

Figure III - Lateral sequence of environments and sediments in the Phosphoria sea (Cheney and Sheldon, 1959)

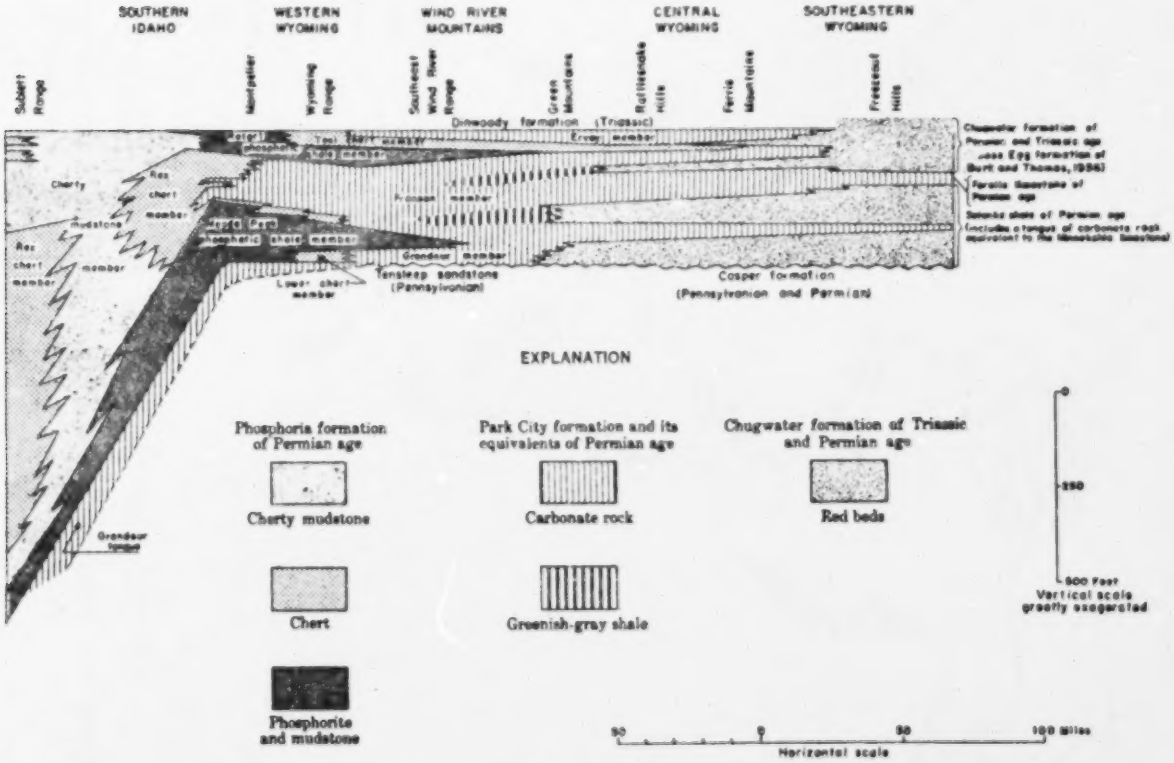

Figure IV - Stratigraphic relations of the Phosphoria, Park City, and Chugwater formations in Idaho and Wyoming (McKelvey and others, 1959).

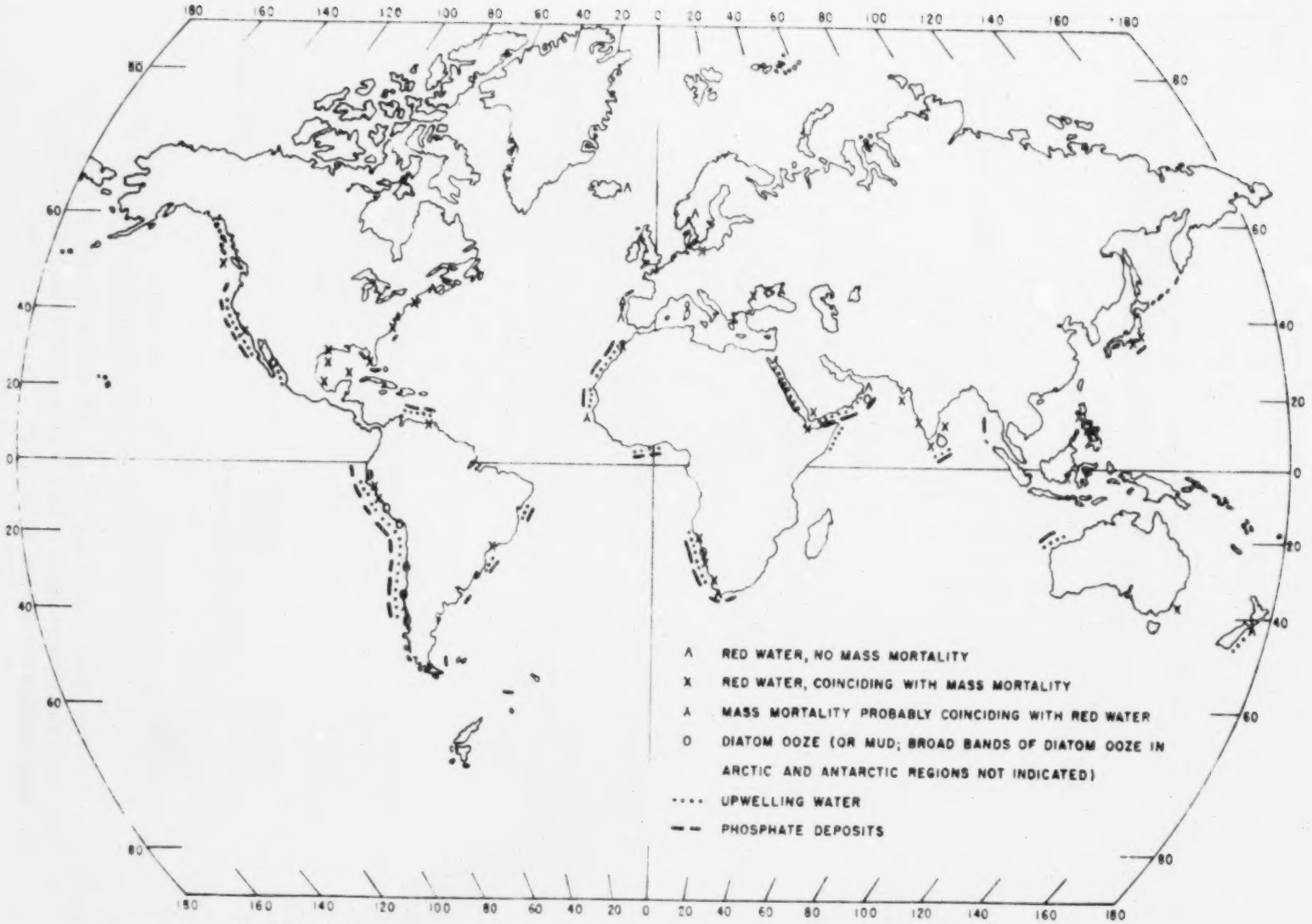
A RED WATER, NO MASS MORTALITY
X RED WATER, COINCIDING WITH MASS MORTALITY
A MASS MORTALITY PROBABLY COINCIDING WITH RED WATER
O DIATOM OOZE (OR MUD; BROAD BANDS OF DIATOM OOZE IN ARCTIC AND ANTARCTIC REGIONS NOT INDICATED)
UPWELLING WATER
PHOSPHATE DEPOSITS

Figure II - Distribution of upwelling water and related phenomena in modern oceans (modified Brongersma-Sanders, 1957, to include data on the distribution of phosphate deposits)

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